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Surveillance Potential of an HF Radar

[Unclassified Title]

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December 1, 1971

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ABSTRACT
(Secret)

This report discusses results of two OTH experiments in which the NRL Madre radar was deployed as an ocean surveillance sensor to monitor aircraft movements in the vicinity of U.S. naval fleet units. The first experiment consisting of day-long exercises was conducted on 14 and 15 May 1970 and involved planned deployment of U.S.S. *Wasp* aircraft and accompanying ships when 700 to 1000 n.mi. from the radar site. In the other experiment of shorter duration on 20 June 1970, the Madre radar supplied unidentified aircraft position information to the U.S.S. *Saratoga* when under illumination at a range of 950 n.mi. These experiments demonstrated the feasibility of using OTH sensing for the protective surveillance of fleet units maintaining radiation silence. This capability should be examined for operational use by the total deployed naval fleet.

PROBLEM STATUS

This is an interim report on one phase of a continuing NRL Problem. Work is proceeding on this and several allied subjects.

AUTHORIZATION

NRL Problem R02-23
Project RF05-151-402-4007

Manuscript submitted September 14, 1971.

SURVEILLANCE POTENTIAL OF AN HF RADAR

INTRODUCTION

(S) The Naval Research Laboratory achieved its initial over-the-horizon (OTH) detection of ships in 1968. An elaboration of such a detection capability has been the observation and simultaneous detection of aircraft and surface vessels under common illumination. That an OTH radar system could provide U.S. fleet units with remote surveillance, for the purpose of alerting such units of possible air threats, has been demonstrated in 1970.

(S) This report discloses the results (reduced to date) of two recent OTH experiments in which the NRL Madre radar was deployed as an ocean surveillance sensor to monitor aircraft movements in the vicinity of U.S. naval fleet units. The first experiment consisting of day-long exercises was conducted on 14 and 15 May 1970 in cooperation with the staff of Commander Carrier Division 14 (ComCarDiv 14) aboard the U.S.S. *Wasp* (CVS-18), which experiment involved planned deployment of U.S.S. *Wasp* aircraft and accompanying ships when 700 to 1000 n.mi. from the radar site. In the other experiment of shorter duration on 20 June 1970, the Madre radar supplied unidentified aircraft position information to ComCarDiv 6 staff members aboard the U.S.S. *Saratoga* (CVA-60) when under illumination at a range of 950 n.mi.

BACKGROUND

(S) Since the installation of megawatt transmitter power in 1961, NRL has been active in detecting and tracking OTH aircraft targets (1-3). Detection capability was further enhanced with the addition of the ARPA-funded 60-dB signal processor in 1966. With the augmented processing dynamic range, slow target detection and tracking became a reality, permitting a continuous 4-1/2-hour track of the U.S.S. *Forrestal* in the summer of 1968 enroute to Mediterranean Sea deployment (4).

(S) A prominent fleet problem at present is that of EMCON (emission control). EMCON forces radiation silence on the ship including the shutdown of its air-search radar system. The constraint of EMCON is often necessary in order that a fleet unit not betray its presence to an enemy ELINT (electronic intelligence) sensor. By the same token, due to the shutdown of its own active sensors, the fleet unit is unaware of a hostile element unless such fleet unit has warning from other sources. This undesirable operational feature prompts the suggestion that an OTH radar, with aircraft and ship detection capabilities, might render a surveillance of fleet units under EMCON and alert such units when aircraft or ships are moving nearby or on a closing course. It was the purpose of the two experiments to be described to demonstrate the feasibility of OTH sensing, with simultaneous (consistent with target fading) detection of surface units and aircraft and the passing of necessary real-time warnings to the unwary ships.

(S) Presailing conferences were held with staff members of ComCarDiv 14 (*Wasp*) and ComCarDiv 6 (*Saratoga*) to work out the procedures for reporting ship positions and the radio communication format. The format decided on was that messages should be passed using a simple coding scheme on an HF single-side-band voice link. Additional time was spent with the *Wasp* personnel to shape the exercise plan which would ultimately involve all surface units in company with the *Wasp* and air units.

U.S.S. *WASP* EXERCISE, 14 AND 15 MAY 1970
(Secret Heading)

Experimental Plan

(S) Enroute to the Azores from fleet maneuvers near Bermuda, the *Wasp* and ships in company were to modify their course to bring the group under illumination from the NRL high-gain antenna at a radar range of 700 to 1000 n.mi. For the two test days the group would separate into two smaller groups with three destroyers (Lakeland group) leading the carrier and the other three destroyers (Sinclair group) by approximately 100 n.mi. These two ship groups upon commencing the actual exercise would maintain a 25-knot speed on a radial path away from the radar, resulting in a 25-knot velocity component along the radar beam. The 25-knot velocity was requested to hopefully insure that the ship groups would be discernible spectrally outside the clutter bandwidth.

(S) If the clutter spectrum inhibited ship detection, provision was made for launching a helicopter from the carrier prior to the actual exercise onset. This helicopter, of the SH-3 type, would fly from the carrier to the forward group. Upon arrival it would take up station and fly rectangular orbits which would continue for the endurance of the helicopter. If the forward group of ships would not be directly discernible, it would be presumed that the helicopter due to its higher speed (60 to 80 knots while in orbit) would be distinguishable and hence mark the location of the ship group. The first helicopter launched would be called Angel 1, with Angel 2 being a relief.

(S) After launching the helicopter, the *Wasp* would launch, one at a time, four S2-E aircraft which would comprise the bogey group. These four aircraft would perform certain staging orbits, and when all were in desired formation the group would depart the carrier for the Lakeland group on a radial path from the NRL radar site at a flight altitude of 3000 to 4000 feet and at a speed and hence velocity of 140 knots. To prevent their visual detection by the Lakeland group the bogey group would descend to 300 feet altitude at the proper time and continue their inbound simulated raid. The Lakeland group during this time would be EMCON constrained. When NRL would acquire the bogey enroute to the Lakeland group, a radio message would be passed from NRL to Lakeland group, via relay through the *Wasp*, advising of the impending attack. In general the information passed would indicate the separation distance between the bogey and ship group as well as whether the separation was increasing or diminishing. When the separation distance would diminish to a specified critical value, the *Wasp* would authorize that the Lakeland group energize its radars and confirm the presence of the bogey. After passing overhead of the Lakeland group, the bogey would turn and run a mock raid against the Sinclair group. Similarly a real-time warning was to be passed from NRL on the acquisition of the bogey enroute to the Sinclair group. The S2-E aircraft have sufficient endurance to permit them to shuttle back and forth through two complete circuits (four penetrations), two on each ship group. Before completing their second run on the carrier, an additional four S2-E aircraft of the relief bogey group would have been launched and staged and ready to depart the carrier for penetration run 5 or bogey 5. During bogey 5 the first group of four S2-E aircraft would be recovered by the carrier. Eight such penetrations were to be flown each day, with the target ship group in each instance being EMCON constrained until a radio message from NRL would warn of impending attack, after which the shipboard radars would be turned on.

(S) An E-1B aircraft, with substantial endurance, would be launched from the *Wasp* prior to the formation of the first bogey. It would then fly to some vantage point from which it could maintain surveillance over all aspects of the exercise. Occasionally position reports for the E-1B aircraft were to be passed from the *Wasp* to NRL.

Detection Results

(S) The NRL Madre radar was deployed in surveillance of mock penetrations following the preceding plan on 14 and 15 May 1970. The radar operating frequency was maintained between 13.5 and 18.2 MHz for the two days. Propagation was supported by an E-layer mode. The ship targets were in the region 750 to 950 n.mi. from the radar during the two days' operations. Penetration warning messages were passed only on 14 May 1970. Reduced data for only May 14 are available for this reporting. Preliminary reduction of the test data for 15 May indicates that both ship groups and several penetrations (four of six flown) were detected but with appreciably lower signal-to-noise levels than on 14 May. Because the target echoes were weak, warning messages were not passed.

(S) Figure 1 shows the course of the *Wasp* and company and general exercise area as denoted. The two ship groups sailed away from the radar for a good part of the first day and then turned and followed a reciprocal course. This was intended to keep them inside of 1000 n.mi. for both days' operations.

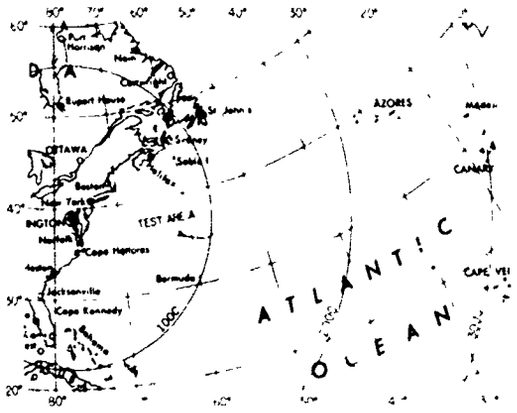

Fig. 1 (S) - Test area for the U.S.S. *Wasp* group experiment of 14 and 15 May 1970

(S) Figure 2 depicts the ship-group configuration for their outbound motion during the first part of 14 May. The ship groups were separated about 70 n.mi. The ships in the Lakeland group were aligned approximately 1000 yards abreast. In the Sinclair group the *Wasp* was flanked on either side by a destroyer at a separation of 1000 yards; a third destroyer followed at a separation of 2000 yards to provide a rescue capability for downed aircraft. The dashed lines in Fig. 2 are the intended penetration courses of the bogey group. Actually bogey 5 of the first day overflew Lakeland by 30 or more miles and then turned around to return to Sinclair as bogey 6 (the sixth penetration run).

(S) Figures 3 through 6 are reproductions of the radar signal processor doppler-versus-range display for specific times during the early part of the first day's operation. This signal processing mode is accomplished by offsetting the zero-frequency IF by half the available doppler bandwidth. For an operating PRF of 80 pps, an offset of 20 Hz is chosen. This permits unambiguous doppler analysis of ±20 Hz, which accommodates approaching and receding targets with doppler shifts to 20 Hz. All carrier aircraft flown during the exercise exhibited doppler shifts less than 20 Hz. In all four figures the earth echo is seen centered on the zero frequency, corresponding to the radar carrier frequency. The spectral width of the earth echo is seen to vary with range.

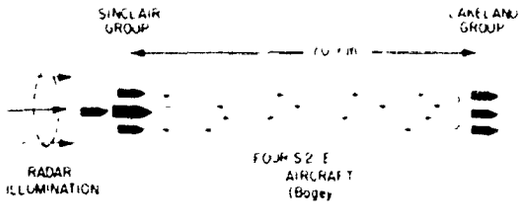

Fig. 2 (S) - Configuration of the two groups of ships for the OTH surveillance exercise of 14 May 1970

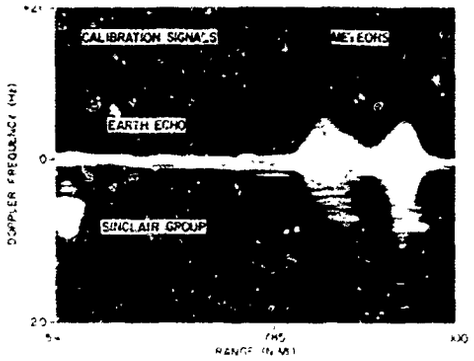

Fig. 3 (S) - Display for the detection of the Sinclair group (25-knot receding velocity) at 142123 GMT

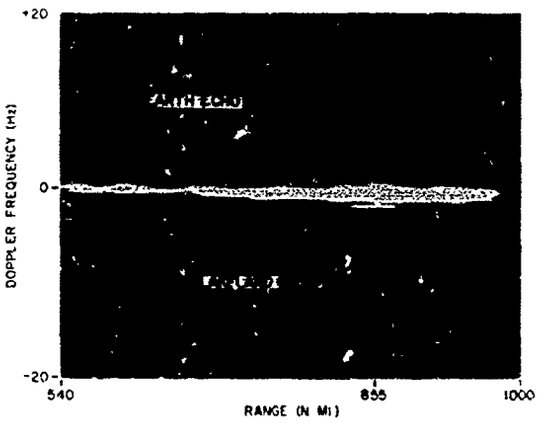

Fig. 4 (S) - Display for the detection of the Lakeland group (25-knot receding velocity) at 141725 GMT

(S) Figure 3 is the doppler-versus-range frame for 142123 GMT. In it the Sinclair group is located on the range strobe at 785 n.mi. and on the doppler strobe at -1.4 Hz which corresponds to 25 knots receding. Calibration signals appear at a doppler of +8.0 Hz and at ranges of 575 and 800 n.mi. Meteor echoes apparent at ranges in excess of the Sinclair group.

(S) Figure 4 is the doppler-versus-range record for 141725 GMT, which shows Lakeland at a range of 855 n.mi and a doppler of -1.4 Hz, corresponding to 25 knots receding. The calibration signals are not seen in this frame because the ship echo was much stronger than the calibration signal. Video levels were set to accommodate the ship target.

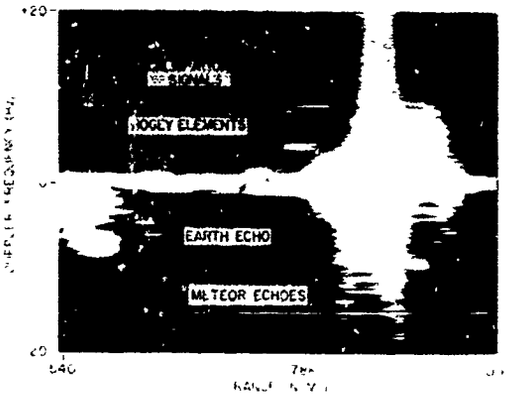

Fig. 5 (S) - Display for the detection of two S2-E aircraft in orbit around the Sinclair group at 141855 GMT The aircraft velocities are on the approach side in the display at 64 and 76 knots

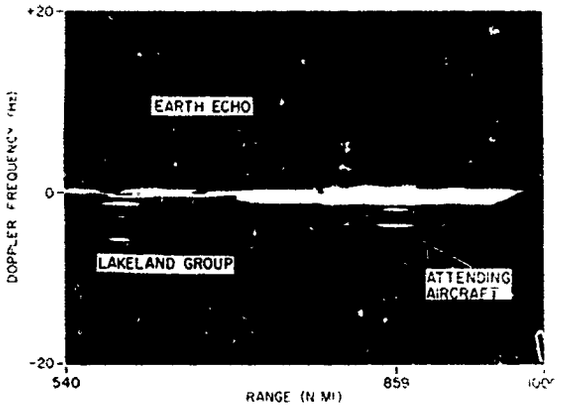

Fig. 6 (S) - Display for the detection of the Lakeland group and an attending aircraft which is receding at 66 knots (142448 GMT)

(S) Figure 5 is the doppler-versus-range record for 141855 GMT. It shows neither the Sinclair group nor the Lakeland group but rather two of the S2-E aircraft in their staging sequence at the range of the aircraft carrier *Wasp*, which at this instance was 788 n.mi. Both aircraft possess approach velocities. The slower aircraft has a radial velocity of 64 knots and the other a velocity of 76 knots. These velocities are less than the cruising speed of the aircraft and indicate that at this particular time these two aircraft were in a turn as part of the staging orbit.

(S) At ranges nearer than the two bogey aircraft there are two prominences on the approach edge of the clutter echo which could be other ship echoes. They possess realistic velocities of 20+ knots. It is conceivable, considering the large expanse of ocean surveyed, that other ship targets would be illuminated. Some of these ships would no doubt, possess sufficiently high velocities to be detectable.

(S) Figure 6, for 142448 GMT, shows the Lakeland group at a range of 859 n.mi. and receding at a velocity of 25 knots. The attending aircraft at the same range under the doppler strobe at -3.7 Hz, corresponding to a receding velocity of 66 knots, is believed to be the E-1B aircraft launched from the *Wasp* prior to the commencement of the exercise to observe the total exercise.

(S) Figure 7 is a 2-minute range-gated doppler-versus-time readout spanning the time 143950 to 144150 GMT, with the range sample taken at 776 n.mi. This frame embodies the detection of three exercise targets: the Sinclair group, bogey elements, and an SH-3

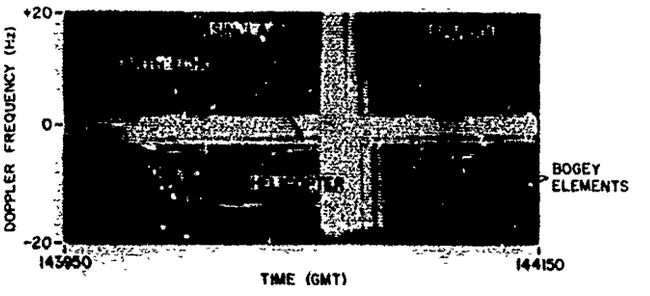

Fig. 7 (S) - Range-sampled display for the detection of the Sinclair group, the SH-3 helicopter accompanying the carrier as a lifeboat, and elements of the bogey group. The range sample point is 776 n.mi.

helicopter. The Sinclair-group echo is noted as a discrete line on the recede side of the earth echo. The helicopter signature line separates from the Sinclair-group line at a point approximately 20 to 25 seconds into the record and continues as a discrete and separate velocity line until the spurious signal at about 1441 GMT. This helicopter is probably the one that is deployed to fly as a lifeboat to the rear and to one side of the carrier during launching and recovery operations. It tracks the carrier's velocity, remaining stationary with reference to the flight deck. The reason it was breaking step at this time is unknown. The third target ensemble of interest in Fig. 7 is the bogey, which can be interpreted loosely either as one or more of the S2-E aircraft up to and including four. The number of aircraft in the group at this time is uncertain. The doppler time record shows that there are at least two. The bogey echo appears as an approximately constant velocity line (-11.5 Hz to -12.5 Hz) on the recede side of the doppler zero. It persists with fading behavior from the left edge of the record to a point slightly to the right of the strongest spurious signal. At this time the bogey velocity line splits, with at least one aircraft entering a turn (diminishing velocity) and the other increasing its velocity slightly. The turning aircraft appears to assume zero doppler prior to 144150. The mechanism of the short-term fading structure of the turning aircraft, though not at present fully understood, is no doubt related to aircraft aspect as well as turning rate. The spurious signal noted was caused by the radar tape-deck system.

(S) The data reduction has consisted of endeavoring to build tracks for each of the target types from range data points taken from the doppler-versus-range readout. This has been tedious. All such points have been segregated according to velocity. For the analysis of the data from the 14 May exercise hundreds of data points have been extracted. Only a sampling of these many points appears in Fig. 8, which in a range-versus-time format depicts the ground tracks of both ship groups (solid lines) and the trajectories (as reported by the *Wasp*) of the eight bogey penetrations (dashed lines). The squares indicate radar estimates of bogey positions which were passed in real time as warning messages to the ship group under mock attack. As can be seen, warnings were passed on only five of the penetration runs. Unfortunately equipment outages precluded reliable real-time assessments of target location on the other three. Postexercise analysis, however, reveals that bogey detections, some for only a few minutes, were accomplished for all eight penetrations. In addition to passing bogey warnings to the ship groups, NRL relayed real-time positions to the *Wasp* on two unidentified aircraft known only as "strangers."

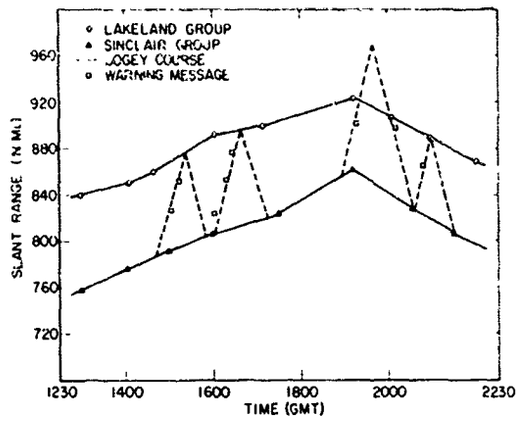

Fig. 8 (S) - Summary of the OTH radar detections during the *Wasp* group experiment including the bogey positions passed in real-time warning messages to the target ship group. The dashed lines are the bogey courses as reported by the *Wasp*.

The *Wasp* acknowledged stranger traffic and confirmed the NRL positions with their own detections. The stranger aircraft were high-performance aircraft with velocities in excess of 500 knots.

(S) Table 1 is a resume of the real-time warnings passed indicating the time of the message, the bogey or penetration number, the range to the target ship, and the bogey position as reported by the *Wasp*. These warning messages correspond to the squares in Fig. 8. In comparing the last two columns of the table, it can be seen that the NRL estimates determined by OTH sensing differed no more than 10 miles from the positions reported by the ship. The average difference for the eight comparisons is less than 6 miles.

Table 1 (S)
Resume of the Eight Warning Messages (Fig. 8) Showing the Comparison of the NRL Estimates Passed in Real Time and the Positions Reported by the *Wasp*

Time (Hours GMT)	Bogey No.	Range to (n.mi.) Target Ship	
		By OTH Radar	Reported by the *Wasp*
1503	1	43	34
1515	1	18	13
1603	3	64	74
1618	3	39	43
1624	3	17	21
1919	5	22	14
2012	6	64	58
2048	7	28	28

U.S.S. *SARATOGA* EXERCISE, 20 JUNE 1970
(Secret Heading)

Experimental Plan

(S) In response to NRL's request the U.S.S. *SARATOCA*, enroute from its base at Mayport, Florida, to the Azores, was to divert from its intended course to intercept the Madre phased-array illumination to the north of Bermuda at a range of approximately 950 n.mi. The ComCarDiv 6 staff stated that flight activity was planned for the Azores area and fuel commitments would not permit any other air work. It was agreed that the *Saratoga* would accommodate occasional NRL requests for increase in ship's velocity to 25 knots while within detection range. Ship's position and weather reports giving sea state, wind direction, and wind velocity would also be passed over the HF SSB communication circuit. NRL, while holding the U.S.S. *Saratoga* under surveillance, would relay to the ship the distance between the ship and any aircraft in its vicinity as a range difference along the main beam axis of the radar. The NRL radar is deficient in that it cannot easily separate two targets in azimuthal angle if they are less than a beamwidth apart. The best estimates of range difference exist when both targets are on the radar beam axis. Inasmuch as the ship's position would be known, the radar beam was to be maintained on the ship. Targets off the beam axis are reported nearer to the ship than they are. The error is greater for those targets further removed in angle from the beam axis.

Detection Results

(S) The U.S.S. *Saratoga* intercepted the NRL OTH radar beam illumination on 20 June 1970 at a range of approximately 950 n.mi. She was proceeding on base course toward the Azores at 12 knots. After attempting a detection of the ship at this slow speed for more than an hour without success, NRL requested that the *Saratoga* advance her speed to 25 knots. Compliance with this request came at 1530 GMT. A 25-knot speed was maintained until 1630. Propagation was achieved with E-layer support.

(S) During the high-speed run of the *Saratoga*, two aircraft were detected, one on an opening course from the carrier and the other on a closing course to the carrier with both aircraft closing range to NRL. NRL relayed, in real time, position information (radial separation) on both aircraft to the carrier. The *Saratoga* confirmed detection of the opening aircraft. A position on the closing aircraft was passed to the *Saratoga* when the aircraft was 120 n.mi. distant from the carrier. The *Saratoga* could not confirm the second aircraft's presence until it approached much closer. NRL passed position information to the *Saratoga* on the second aircraft until it was at least 50 miles on the NRL radar side of the ship.

(S) Figure 9 is a sequence of pictures of the doppler-versus-range display that show the vagrant aircraft at various ranges from the radar and from the carrier for the times indicated. The vagrant aircraft closed range with respect to the radar from 1027 to 918 n.mi. during the 30-minute sequence. Other echoes are possibly one approaching surface vessel and one receding surface vessel other than the *Saratoga*. The system calibration signal is barely visible at 970 n.mi. at a doppler corresponding to 16 knots on the approach side.

(U) The resonant wave structure of the sea echo can be seen at the near and far regions of the earth echo. The two parallel doppler lines correspond to the echoes from the approaching and receding resonant waves on the surface of the ocean.

(S) Figure 10 is a schematic showing the location of the vagrant aircraft of Fig 9 at 1610 GMT with respect to the *Saratoga* and to the OTH radar site. The center of

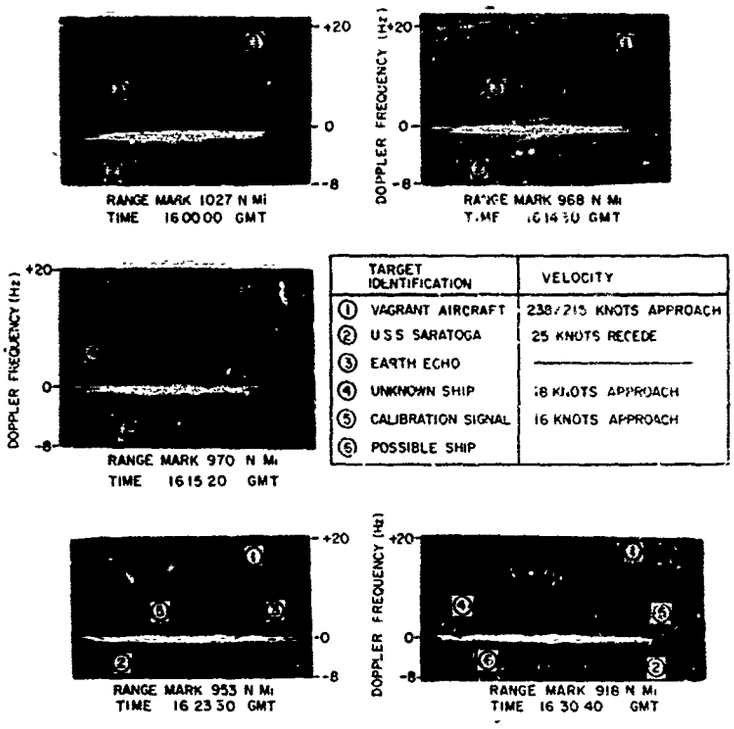

Fig. 9 (S) - Sequence of the display of video doppler frequency versus range depicting the motion of a vagrant aircraft from 1027 n.mi. to 918 n.mi. during the *Saratoga* exercise. The range extent for each figure is 600 to 1250 n.mi.

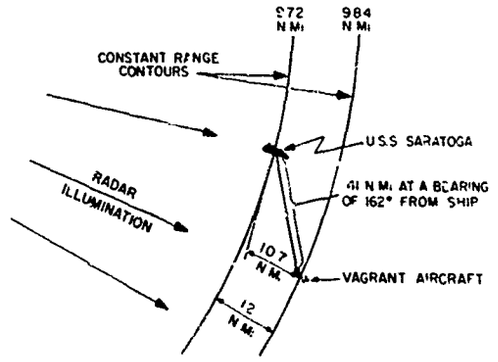

Fig. 10 (S) - Comparison of detection geometry for a vagrant aircraft at 1610 GMT

the two arcs is at the OTH site. At 1610 GMT NRL was holding the *Saratoga* in detection at a slant range of 972 n mi. and the vagrant aircraft in detection at a slant range of 984 n.mi., the radial separation being 12 n.mi. The *Saratoga* advised that she was holding the vagrant under detection at a range of 41 n.mi. from the ship on a bearing of 162°

true from the ship. On the basis of the ship's reported position of the vagrant, the aircraft was 10.7 n.mi. further away from the radar site than the ship. This compares quite well with the OTH estimate of 12 n.mi.

(S) NRL had been briefed prior to the sailing of the *Saratoga* that she might during her transit be overflown by Soviet aircraft. Identity of the vagrant aircraft was not supplied to NRL by the *Saratoga*. In an effort to ascertain the vagrant identity NRL secured all flight strips for the day of interest, for the area of interest, from the North Atlantic Air Traffic Control Center at Gander, Newfoundland. Upon processing these position reports in the NRL computer and submitting the results to screening, a likely suspect emerged. The vagrant aircraft is believed to be a Royal Air Force C-130 aircraft, flight RR3268, enroute from England to Kindley Air Force Base, Bermuda. Its track and velocity profiles closely match those of the detected vagrant aircraft.

(S) As mentioned earlier the *Saratoga* had advanced her speed to 25 knots to permit her ready detection. At 1630 GMT the ship slowed to her 12-knot course speed. Figure 11 is a range-gated doppler-versus-time record showing the deceleration of the *Saratoga*. The record is more than 13 minutes long, with the earth echo centered on 0 Hz. A calibration signal is at 1 Hz on the approach side of the clutter, corresponding to a radial velocity of 17+ knots. The spurious signal again is due to tape-system parity errors. The *Saratoga* can be seen prior to 1631 GMT as an intermittent (due to fading) constant-doppler line below the earth echo. The velocity appears to begin decreasing at 1631 and continues to do so until it becomes merged with the earth echo shortly after 1637. The doppler threshold for target discernibility is 14 knots.

RECAPITULATION

(S) With the cooperation of operational fleet units of the U.S. Navy, NRL has been able to demonstrate the feasibility of using an OTH radar as a surveillance sensor with the desired feature of a real-time warning reaction.

(S) For those fleet units constrained under EMCON, NRL warning messages provided dependable alerts, prior to the time that the ship could itself acquire the air target. Separation estimates were consistent with indications by air-search radars on the ships. Deficiences in the assessment of off-axis targets by the Madre radar could be corrected with state-of-the-art improvements in angle resolution.

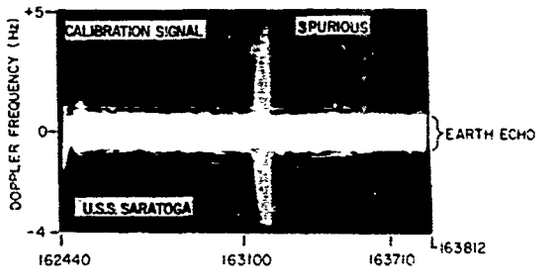

Fig. 11 - Range-sampled record of the doppler frequency during the slowdown of the U.S.S. *Saratoga* from 25 to 12 knots. The range sample point is 961 n.mi.

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(S) If a tactical situation had existed and EMCON constraints were in order, the OTH sensor would have been the only source of bogey warnings to the fleet units.

(S) This capability should be examined for operational use by the total deployed naval fleet, as soon as possible.

FUTURE WORK

(S) Investigations are continuing in several areas pertinent to ocean surveillance as a service to surface units of the U.S. Navy. Some of these are:

(S) • A comparison of the amplitude and doppler behavior for a group of ships with that for a single ship to determine whether the radar cross section and spectral behavior might lend itself to assessing the number of ships in a group.

(S) • An evaluation of different transmitted pulse waveforms in order to enhance the signal-to-clutter levels for OTH ship detections and thus extend detection to lower doppler thresholds.

(S) • An examination of the merits of monostatic/bistatic monopulse reception as a means of enhancing the signal-to-clutter levels for ship targets.

(S) • A determination of the HF radar cross section of the SH-3 helicopter in order to evaluate its use in flagging the position of a surface unit proceeding at a speed too slow to be directly detected by the OTH sensor.

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13. ABSTRACT

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This report discusses results of two OTH experiments in which the NRL Madre radar was deployed as an ocean surveillance sensor to monitor aircraft movements in the vicinity of U.S. naval fleet units. The first experiment consisting of day-long exercises was conducted on 14 and 15 May 1970 and involved planned deployment of U.S.S. *Wasp* aircraft and accompanying ships when 700 to 1000 n.mi. from the radar site. In the other experiment of shorter duration on 20 June 1970, the Madre radar supplied unidentified aircraft position information to the U.S.S. *Saratoga* when under illumination at a range of 950 n.mi. These experiments demonstrated the feasibility of using OTH sensing for the protective surveillance of fleet units maintaining radiation silence. This capability should be examined for operational use by the total deployed naval fleet.

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